The feasibility and acceptability of a home based exercise intervention for colorectal cancer survivors: 'EXACT' – EXercise And Colorectal Cancer Trial'

Title page

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Abstract

Background: Improving lifestyle factors, including increased physical activity and exercise is associated with improved outcomes in colorectal cancer care and treatment. The purpose of this research was to assess efficacy and feasibility of a home based exercise intervention in colorectal cancer survivors (CRCS).

Methods: CRCS were recruited to a 12-week multimodal exercise intervention with individualised goal setting. Physiological, psychological and biological outcomes were assessed at baseline, post-intervention (week 12) and follow up (week 24). The feasibility and acceptability of the intervention was measured by recruitment, adherence and retention rates as well as participant satisfaction questionnaires.

Results: Twenty-three stage I-IIIb CRC survivors volunteered for the research (65.7% recruitment rate). The majority were male (69.6%) with stage IIa CRC (47.82%) and 24-months post treatment. 91.6% of participants completed the intervention, of which 70% completed 219 ±108 minutes per week moderate-to-vigorous intensity exercise. Results showed favourable changes to anthropometric measures with clinical improvements in cardiovascular fitness and lower body strength. These changes were in the absence of changes to blood biomarkers.

Conclusion: This 12-week multimodal intervention was feasible and acceptable to CRCS and produced favourable changes to cardiovascular fitness and increases in moderate intensity PA. These findings should help inform supportive care and clinical practice in CRCS.

Keywords: biomarkers, survivorship, physical activity, lifestyle, energy balance

Trial registration: the trial is registered on clinicaltrials.gov with the identifying code of: NCT02607787.

Introduction

For several years, the link between colorectal cancer (CRC) and exercise has been widely investigated and exercise has been shown to play a role in both the primary and secondary prevention of cancer.[1,2] The evidence from over 50 observational studies suggest that regular physical activity, independent of BMI, decreases the risk of CRC occurrence by approximately 40%[3]. Epidemiological evidence also supports this preventative effect[4,5]**. In a meta-analysis of six prospective cohort studies within colectral cancer survivors (CRCS), those who engaged in high versus low physical activity after diagnosis had a 42% lower risk of total mortality and 39% lower risk of colorectal cancer–specific mortality[6].** Whilst prospective and case-control studies have highlighted an inverse association between physical activity and risk of colon cancer, it is unknown whether the current recommendations of 150 minutes moderate intensity exercise[7] are safe, acceptable and feasible in CRCS. **There is also a paucity of research examining the behavioural and physiological effects by which exercise may exert its positive effects on clinical end points including cardiovascular fitness and blood biomarkers[8].** The use of such biomarkers can help determine the mechanisms underlying the benefits which exercise elicits on recurrence or progression of cancer[9]. This information can also provide a measurable indicator of the progression of a participant throughout an exercise intervention and enable better individualisation and precise prescription of personalised programmes to maximise supportive cancer care and rehabilitation for the individual. Whilst there can be disadvantages to home-based exercise interventions, they offer the opportunity to continue with patient rehabilitation particularly during the current COVID-19 pandemic, when access to facilities is restricted. **They have several advantages over supervised facility based interventions including: a lack of reliance on costly equipment or facilities, no need for transportation to participate and the flexibility of scheduling the activity to the participant's desired schedule[10,11].** Equally, home-based interventions can be more cost effective than supervised or facility based programmes[11]. The exercise and colorectal cancer trial' (EXACT) study was a home based multimodal exercise intervention with the primary aims of assessing the feasibility, acceptability and biologic effects of an exercise intervention for CRCS. Our primary hypothesis was that the intervention would be safe, feasible and acceptable and that exercise would elicit improvements in cardiovascular fitness, anthropometric measures and blood biomarkers; with the overarching aim of informing a full-scale RCT similar to the work of Brown and colleagues[8]. This study has contributed to the body of knowledge surrounding home-based exercise in CRC survivors in terms of feasibility, acceptability and biological markers. As such we feel the aim of the research has been achieved to some degree.

Materials and methods

Study design

The EXACT study was a 12 week home based multimodal exercise intervention, comprising of behaviour change and exercise in CRCS in Northern Ireland. The design of the intervention was informed by Medical Research Council (MRC) guidelines for developing complex interventions[12] and a systematic review of the use of biological markers as an outcome of exercise[13]. The 'Behaviour Change Wheel' (BCW) was chosen as the framework for the development of the intervention[14]. The exercise intervention itself, including the activity booklet and diary concept, was adapted from previous work by our research group[15, 16, 17].

Participants

Participants were eligible if they were Dukes A-C colorectal cancer patients at least 6 weeks post any-type of anticancer treatment; over 18 years of age; physically able to undertake the intervention without use of a walking aid[15]. Patients still undergoing and/or scheduled for further anti-cancer treatment, those with cognitive impairment or known co-morbidities which impact physical functioning or nutritional status and those already meeting the current recommended physical activity guidelines[18] were excluded from participation. 2301 patients were screened from a patient group treated at a regional cancer centre, with 70 highlighted as being potentially eligible. Of these, 35 (50%) were referred to the researcher (see figure I).

Randomisation

After providing informed consent, participants were randomly allocated to usual-care control or exercise intervention (see figure II) using a computer generated random allocation. It was not possible to blind the participants or primary researcher.

Intervention

An educational booklet was designed which included motivational prompts, solutions to potential barriers and information on how to exercise safely and at the right intensity using the Borg scale[19]. Both the walking and strengthening exercises were outlined week by week, with the aim of participants eventually reaching the goal of at least 150 minutes a week of moderate intensity aerobic activity i.e. walking at least 30 minutes on at least 5 days a week, and a strengthening goal of 3 sets of 8-15 repetitions, 2-3 days a week[18]. An exercise diary was used to self-report the amount of exercise completed each week. The information recorded each day included: time spent walking, the number of steps completed (Yamax Digi-walker pedometer (Yamax Corp., Kumamoto, Japan), the number of sets and repetitions completed and any barriers experienced.

Group 1: The Intervention Group

Following a standard fast, participants attended for baseline assessment. In addition to completing the outcome measures, participants in the intervention group received a one-to-one exercise consultation based on the BCW. During this consultation, the exercise booklet and diary were explained and their individual exercise intervention was devised. Although this was a home-based intervention, support was provided in the form of weekly researcher telephone calls to record the level of adherence (by pedometer step counts) and to seek confirmation of the completion of the strengthening component. These documented phone calls also served to address any exercise barriers and suitable exercise goals were agreed for the following week. On completion of post intervention assessments, participants completed one additional consultation aimed at promoting long term maintenance of physical activity (PA).

Group 2: The Control Group

Previous studies have experienced high contamination i.e. increase in activity levels within the contact control groups and thus a non-contact control group was implemented in this study[15.] Participants randomised to this group had the same number of visits at the same time points, as depicted in Figure II. However they did not receive the one-to-one exercise consultation and intervention information, including the booklet, diary and pedometer, until their final visit at week 24 follow-up. They did not receive weekly phone calls and continued with their usual care.

Outcome measures

Physiological, psychological and biological outcomes were assessed at 3 time-points; baseline (week 0), post-intervention (week 12) and follow-up (week 24). Physical activity was measured over a 7 day period (using triaxial accelrometry Actigraph 'GT3x' ActiGraph, Pensacola, FL, USA). Physiological data included: anthropometric measures (height and weight, waist and hip circumference), strength and endurance of the lower extremity muscles (timed sit-to-stand (STS) test) and cardiovascular endurance (six minute walk test (6MWT). Blood biomarkers relating to *metabolism* (insulin like growth factor I (IGF-I), IGF binding protein 3 (IGFBP-3), glucose, total cholesterol, high density lipoprotein (HDL) cholesterol, triglycerides), *inflammation* (c-reactive protein (CRP), tumour necrosis factor (TNF-a), interleukin-6 (IL-6), leptin, adiponectin), *immunity* (full blood count) and *DNA damage* (COMET assay) were also measured.

Feasibility and Acceptability

The feasibility of implementing this intervention in a clinical environment was assessed by monitoring; the number of clinics attended; the number of patients screened/eligible/approached; the number of patients that received and refused the study information; the number of patients who were contacted to inform the researcher whether they would be part of the study or not (reasons why recorded when given). Acceptability was measured by assessing the results of a satisfaction questionnaire given to the intervention participants post intervention (Week 12). Study adherence and completion rates of the weekly phone call were also recorded.

Statistical analysis

Quantitative data was analysed using SPSS version 23 (IBM Corp, USA). Descriptive statistics were used to summarise the data for inter and intra participant outcome measures over time. Independent t-tests were complete to compare the group characteristics and baseline measurement. Between group differences over time in various scores baseline, post intervention (week 12) and follow up (week 24) outcomes was analysed using a linear mixed model. A repeated measures ANOVA (group x time) was used with between group analyses performed using pairwise comparisons with least-squares (LS) means. Results are expressed as treatment effects and 95% confidence intervals. The effect size of the intervention was assessed using Cohen's d (Cohen, 1988) analysis on the mean baseline and week 12 results from the intervention group.

Results:

Baseline characteristics

Twenty-three stage I-IIIb CRC patients consented (65.7%) to participate in the study. The majority of participants were male (69.6%) with stage IIa CRC (47.8). The average age of participants was 62.6 (±9.1) years with an average time since treatment completion of 24 (±18) months (Table I). The majority of participants were retired (60.9%) and had received a combination of surgery and chemotherapy (60.9%).

Physical activity

Data from 50 out of a possible 60 sets of accelerometry data were analysed (83.3%) due to insufficient wear time. The average wear time was 15.1 hours/day for 3.96 days. Exercise prescription variables are presented in table II. There were no significant effects between groups over time for any of the PA measures. Despite this, at baseline 56% of the intervention group were achieving the guideline 150 minutes/week at baseline compared to 38% of the

control group. Over the 12 week intervention period, the average exercise volume at MVPA in the intervention and control groups were 172.5 (130.8) and 142.2 (90.3) minutes per week, respectively (figure III). On an individual basis, between baseline and week 12, seven out of eight valid datasets in the intervention group experienced an increase in MVPA whilst one demonstrated a decrease. In comparison, four of the control group increased their MVPA whilst three decreased MVPA. There was no effect for the intervention group for step counts but a large (*d*=-0.81) effect seen between baseline and week 12 for the control group.

6MWT and sit-to-stand test

Both groups improved exercise capacity scores in the 6MWT and sit-to-stand test however these were not significant. Both groups experienced moderate improvements in the sit-to-stand test at week 12. A large improvement however was seen in the control group for the 6MWT (*d*=-0.98), whilst a moderate effect was reported in the intervention group (*d*=0.77) (table III).

Biological outcome measures

There were no significant changes from baseline to post intervention in any of the blood biomarkers (supplementary table II). A moderate improvement was seen for total cholesterol in the intervention group (d=0.56) compared to no effect in the control (d=0.02) at week 12. This was accompanied by a large effect for LDL cholesterol in the intervention group (d=0.87) vs a small change in the control group (d=0.37). Control group HDL cholesterol increased more favourably vs intervention (d=0.62 vs d=0.19 respectively). Blood glucose concentration (BGC) increased in the control group at each time-point (6.2+1.4, 6.28+2.0, 7.2+2.5) whereas it decreased in intervention (6.6+2.5 vs. 6.5+2.7) before returning to 7.0+1.3 mmol.l-1 by follow up.

DNA damage

There were no significant changes in DNA damage between any time-point (see supplementary table I). There was a moderate effect in the intervention compared to a small effect in the control group at week 12 (d=0.75 and d=0.35 respectively). The intervention group values increased in comparison to the control group (229.51±56.83µm to 287.2±93.3µm versus 202.4±107.5µm to 233.0±60.5µm) and had a greater decrease at week 24 (287.2±93.3µm to 248.9±95.9µm versus 233.0±60.5µm to 228.3±54.2µm) however none of these results were significant.

Anthropometric measures

Small effect sizes were seen for weight (d=0.22), BMI (d=0.24) and waist circumference (d=0.34) in the intervention group at week 12 with all three measures decreasing (supplementary table I). Hip and waist circumference increased in the control group over time ($P<0.05$).

Feasibility and acceptability

Taking into account sessions that were not attended, blood samples were not taken or incomplete for a total of 7 occasions (11.1%). 97.7% of the 12-weekly phone calls were complete with 90.9% of participants recording daily step counts. The average length of the weekly phone calls was 8 minutes 21 seconds per patient. 90.9% of participants recorded their daily activity and step count totals for all 7 days of the 12-week intervention. The results of the satisfaction questionnaire were all positive. When participants were asked; 'Looking back, was there anything that you did not like about the programme?' 100% of participants provided positive comments such as; "No, the programme was educational and easy to follow with the booklet provided. *The Individual delivering the research* was very supportive throughout the programme" and "No- the programme provided an incentive to exercise more - much needed." When asked; 'Can you suggest anyway the programme could consume been made better for you, or for other people taking part in future programmes?' The majority of the participants answered 'no' with additional comments such as; "No, it was professionally put together and motivating for me" and described it as "just right".

Discussion:

The findings from our study suggest that a 12 week home-based multimodal exercise intervention is both feasible and acceptable to colorectal patients who have completed cancer treatment. Exercise was well tolerated and enjoyable, with both the intervention and control group able to complete exercise at moderate-vigorous intensity aligned with current PA guidelines for cancer survivors[15]. Using the National Institute for Health Research (NIHR) description of feasibility, this intervention can be considered feasible for a fully powered RCT. NIHR states that prior to an RCT, studies completed should aim to answer "can this study be

done?"[20].Furthermore, the criterions that need to be recorded in order to answer this question include; the willingness of participants to be randomised; the willingness of the clinicians to recruit participants; the number of eligible participants; the follow-up rates, response rates to questionnaires, adherence/compliance rates; and the time needed to collect and analyse the data[20]. Participants in this study were willing to be randomized with limited drop-out (8.7%) and high recruitment (65.7%) rates. Willingness of the clinicians to recruit participants was also high; with all nine clinicians (4 oncologists; 5 surgeons) dealing with CRC patients in the regional cancer centre voluntary agreed to recruit. Park and colleagues[21] have previously demonstrated that the majority of clinicians agree that exercise is both beneficial (72.8%) and important (69.6%) for patients however, barriers such as lack of time, unclear exercise guidelines for cancer patients and concerns about safety were the most commonly reported reasons for clinicians to not discuss exercise[21]. This also has implications for informing future RCT design. The recruitment rate for EXACT was 65.7% (out of a possible 70 participants identified over a 10 month period). This is very favourable compared to four other similar studies which had rates less than 35%[22, 23, 24, 3, 6] The reason for this high recruitment rate may be attributable to the active role of the researcher at the oncology and surgery clinics, meeting the participant face-to-face from outset of study introduction. Researcher support throughout the study in terms of weekly telephone contact and the study resources (based on previous work by our research group[15, 16, 17]) may also have contributed to the high retention rates for EXACT, with 82.6% of the participants completing all three assessment sessions over the six-month study duration.

In our study, 38% of the control group and 56% of the intervention group were already achieving the recommended level of at least 150 min/week of MVPA at baseline[18]. This is encouraging given the objective measurement of PA *via* accelerometry which is somewhat limited in cancer survivors. Recent work published by Vallance and colleagues[36] in a sample of 181 CRCS revealed that only 15.7% of those sampled were achieving the guidelines for MVPA, so at the outset more than double of the EXACT participants were already achieving the recommended level of PA for health. Our results are similar to the work of Brown and colleagues[8] who examined the dose-response effects of 150 and 300 minutes of aerobic exercise in a home based setting for 6 months. They concluded that higher volumes of moderate-intensity aerobic exercise (up to 300 minutes/week) are feasible, safe, and elicit favourable changes in some prognostic blood biomarkers in CRCS. For EXACT, the favourable trends observed for cardiovascular fitness and anthropometric measures were largely in the absence of changes to the blood biomarkers assessed. The biological pathways by which exercise may influence or reduce the risk of colorectal cancer recurrence and premature mortality have not yet been elucidated[8.] The proposed mechamisms are varied, but include changes in

inflammation, hormones, DNA repair and immune **function[25].** As such, and following a systematic review of the literature[13] the EXACT study sampled a range of investigative biomarkers relating to metabolism, inflammation, immunity and DNA damage in CRC. Whilst our results largely showed no significant changes, it remains undetermined whether these biomarkers would also remain unchanged at higher exercise doses as employed by Brown et al[8] or within a large scale RCT. Despite the positive trends in relation to PA in this study, none of the measures displayed significance over time. In light of the work by Brown and colleagues previously discussed[8], it is possible that exercise tolerance for CRCS might be greater than initially thought. Brown et al demonstrated that a high dose of exercise (300 minutes per week) was tolerable and crucially, produced positive changes to blood biomarkers[8]. We suggest that the results of EXACT further support the argument that PA research in CRCS requires additional resesarch at varying exercise doses and intensities; along with in-depth investigation of blood biomarkers to clearly elucidate the biologic pathways involved. As regular exercise up-regulates mytokine secretion[25] and anti-inflammatory processes resulting in the transcription of nuclear factor-κB (NF-κB) involved in inflammation, immunity, cell proliferation and differentiation a wide range of biomarkers requires investigation.

DNA damage

Recent work by Vodicka et al[26] has clearly documented the potential role of the comet assay as a sensitive and cost-effective technique in investigating DNA damage and repair in cancer patients. Similar to Browns paper[8] which demonstrated that exercise favourably alters oxidative DNA damage, our findings also help to contribute to the knowledge base in colorectal cancer. Given that the percentage of DNA in the tail is directly proportional to the amount of damaged DNA present[27]; intervention values for EXACT were higher (but not significantly) than the control group at baseline. At week 12 this figure increased in the intervention group but decreased in the control; with control group week 24 values remaining stable whilst the intervention values dropped by approximately 10%. To the author's knowledge, no other study has used the comet assay to measure DNA damage within a colorectal cancer PA intervention; only in a longitudinal observational study[28] and in a drug trial in vivo and in vitro[29]. Therefore, baseline data must be compared with non-cancer population studies. Studies that analysed the comet assay on lymphocytes reported findings for % tail length as 5-8% in trained athletes[30, 31] and 30-40% in untrained and/or sedentary participants[32, 33]. The baseline levels for participants in the 'EXACT' study were 30% in the intervention and 24% in the control. Cancer is essentially a disease of DNA and many of the anti-cancer treatments received by participants induce further DNA damage, some of which is later repaired. As participants were on average 24 months post treatment, it is conceivable that baseline levels are within range of the general population. Between baseline and week 24, control group levels remained relatively stable. For

the intervention group, levels increased by 2.8% at week 12 but decreased by over 10% at week 24. None of these changes were significant however so no definitive conclusions can be drawn. Exercise does induce DNA damage[34] but long term exercise can up-regulate the DNA-repair system[35] This may help explain the trend seen in the intervention group however this would require additional research over a longer experimental exercise period and at varying intensities. Certain limitations existed within the present study, including limited capacity (one researcher) to recruit at one (of two) regional cancer centres. Additional resource would have assisted in attending the other clinic and analysing additional blood biomarkers but unfortunately this was outside the scope of the current doctoral project.

Conclusion:

Exercise and physical activity in cancer rehabilitation is an expanding area of research with data from cohort studies suggesting the potential benefits of exercise. This 12-week multimodal intervention and follow up was feasible and acceptable to colorectal cancer survivors and produced favourable changes to cardiovascular fitness and increases in moderate intensity physical activity. These were largely in the absence of changes to blood biomarkers. These results can be used to guide physical therapy recommendations for rehabilitation of colorectal cancer patients, which in turn may benefit patient outcomes post surgery and treatment. Further research is required to enable clinicians to fully understand the biologic pathways by which exercise may ameliorate colorectal cancer progression and outcomes. There is also a need to establish the dose, duration and intensity of exercise required in a clinical or home based setting to alter metabolic, inflammatory, immune and DNA damage biomarkers. In conclusion, the results of the EXACT study can assist in informing clinical recommendations surrounding physical activity for colorectal cancer survivors.

Conflicts of interest/competing interests

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

Ethics approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Office for Research Ethics Northern Ireland (ORECNI) number: 14/NI/1048; Belfast Health and Social Care Trust approval was also received (14127JGT-SS).

Authors contribution

LMcD carried out recruitment and experimental laboratory testing under clinical supervision of JR. AMcN led on the biomarker analysis. JG and MM conceived the project. All members of the team contributed to study design and oversaw statistical analysis. LMcD and AMcN drafted the manuscript for submission. Final manuscript was approved by all the authors.

Corresponding author statement: AMcN can confirm that there will not be any further changes in the authorship which includes either the addition or removal of authors details and he/she will be sole responsible person for all the communications and proceedings that are needed to be done with the publisher (according to the necessity of the publisher) on behalf of all the authors.

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References

1. Giovannucci E, Ascherio A, Rimm EB, Colditz GA, Stampfer, MJ and Willett WC (1995) Physical activity, obesity, and risk for colon cancer and adenoma in men. *Ann Intern Med* 122(5):327-334.

2. Tayyem RF, Shehadeh IN, Abumweis SS, Bawadi HA, Hammad SS, Bani-Hani, KE, Al-Jaberi TM and Alnusair, MM 2013 Physical inactivity, water intake and constipation as risk factors for colorectal cancer among adults in Jordan (*Asian Pac J Cancer Prev* 14(9): 5207-5212.

3. IARC Press, 2002. Working Group on the Evaluation of Cancer-Preventive Agents. Weight control and physical activity. *IARC Sci Publ*. 2002.

4. Wolin KY, Yan Y, Colditz GA. and Lee, IM (2009) Physical activity and colon cancer prevention: a meta-analysis. *Br J Cancer* 100(4): 611-616.

5. Friedenreich CM, Neilson HK, Lynch BM (2010). State of the epidemiological evidence on physical activity and cancer prevention *Eur J Cancer* 1;46(14):2593-604.

6. Schmid, D. and Leitzmann, MF (2014). Association between physical activity and mortality among breast cancer and colorectal cancer survivors: a systematic review and meta-analysis *Ann Oncol* 25(7): 1293-1311.

7. Rock CL, Doyle C, Denmark-Wahnefried W, et al. (2012) Nutrition and Physical Activity guidelines for cancer survivors *CA Cancer J Clin* 62:243-74.

8. Brown JC, Troxel AB, Ky B, et al (2018) Dose-response effects of aerobic exercise among colon cancer survivors: a randomised phase II trial *Clin Col Cancer* 1:32-40.

9. McTiernan A, Schwartz RS, Potter J. and Bowen D (1999). Exercise clinical trials in cancer prevention research: a call to action *Cancer Epidemiol Prev Biomarkers* 8(3): 201-207.

10. Tang MF, Liou TH and Lin CC (2010) Improving sleep quality for cancer patients: benefits of a home-based exercise intervention *Support Care Cancer* 18(10): 1329-1339.

11. Hinrichs T, Bucchi C, Brach M, Wilm S, Endres HG, Burghaus I, Trampisch HJ and Platen P (2009). Feasibility of a multidimensional home-based exercise programme for the elderly with structured support given by the general practitioner's surgery: Study protocol of a single arm trial preparing an RCT *BMC Geriatr* 9(1):1.

12. Craig P, Dieppe P, Macintyre S, Michie S, Nazareth I and Petticrew M (2008). Developing and evaluating complex interventions: the new Medical Research Council guidance *BMJ* 337:1655.

13. McDermott LA, Murphy MH, McNeilly AM, Rankin JP and Gracey J (2018). Biological markers as an outcome measure of exercise in cancer rehabilitation: A systematic review *J Cancer Res Ther*14(2), p.267.

14. Michie, S, van Stralen MM and West R (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions *Implement Sci.* 6: 42.

15. Donnelly C, Lowe-Strong A, Rankin J, Campbell A, Gardiner E, Gracey J (2010) A randomised controlled trial testing the feasibility and efficacy of a physical activity behavioural change intervention in managing fatigue with gynaecological cancer survivors. *Gynecol Oncol* 122:618-624.

16. Payne C, 2015. Rehabilitation in Palliative: A Novel Exploratory Study. PhD thesis, Ulster University Northern Ireland UK.

17. Gracey JH, Watson M, Payne C, Rankin J and Dunwoody L (2014). Translation research: 'Back on Track', a multi-professional rehabilitation service for cancer-related fatigue *BMJ Support & Palliat Care,* bmjspcare-2014.

18. Campbell KL, Winters-Stone KM, Wiskemann J, May AM, Schwartz AL, Courneya KS, Zucker DS, Matthews CE, Ligibel JA, Gerber LH, Morris GS, Patel AV, Hue TF, Perna FM, Schmitz KH. Exercise Guidelines for Cancer Survivors: Consensus Statement from International Multidisciplinary Roundtable (2019) . *Med Sci Sports Exerc.* 2019 Nov;51(11):2375-2390.

19. Schmitz KH, Courneya KS, Matthews C, Demark-Wahnefried W, Galvão DA, Pinto BM et al (2010). American College of Sports Medicine roundtable on exercise guidelines for cancer survivors. *Med Sci Sports Exerc* 42: 1409–26.

20. Borg GA. Psychophysical bases of perceived exertion (1982). *Med Sci Sports Exerc* 14:377-381.

21. NIHR 2016. Evaluation, Trials and Studies – Glossary. [online] Available at: http://www.nets.nihr.ac.uk/glossary?result_1655_result_page=F Accessed 05/12/19.

22. Park JH, Lee J, Oh M, Park H, Chae J, Kim DI, Lee MK, Yoon, YJ, Lee CW, Park, S. and Jones, LW (2015) The effect of oncologists' exercise recommendations on the level of exercise and quality of life in survivors of breast and colorectal cancer: A randomized controlled trial *Cancer* 121(16):2740-2748.

23. Courneya KS, Friedenreich CM, Quinney HA, Fields AL, Jones LW, Fairey AS (2003). A randomized trial of exercise and quality of life in colorectal cancer survivors *Eur J Cancer Care* 1:12(4):347-57.

24. Bourke L, Thompson G, Gibson DJ, Daley A, Crank H, Adam I, Shorthouse A. and Saxton J (2011). Pragmatic lifestyle intervention in patients recovering from colon cancer: a randomized controlled pilot study *Arch Phys Med Rehabil* 92(5):749-755.

25. Lee DH, Kim JY, Lee MK, Lee C, Min JH, Jeong DH, Lee JW, Chu SH, Meyerhardt, JA, Ligibel, J. and Jones, LW (2013). Effects of a 12-week home-based exercise

program on the level of physical activity, insulin, and cytokines in colorectal cancer survivors: a pilot study. *Suppor Care Cancer*, 2013; 21(9):2537-2545.

26. Hojman P, Dethlefsen C, Brandt C, Hansen J, Pedersen L. and Pedersen, BK (2011) Exercise-induced muscle-derived cytokines inhibit mammary cancer cell growth. *Am J Physiol Endocrinol Metab*,; 301(3):E504-E510.

27. Vodicka P, Vodenkova S, Opattova A, Vodickova L (2019) DNA damage and repair assessed by comet assay in cancer patients. *Mut Res Gen Tox En*,; 843:95-110.

28. Kumaravel TS, JHA (2006) Reliable comet assay measurements for detecting DNA damage induced by ionising radition and chemicals. *Mut Res Genet Toxicol Environ Mutagen* 605(1):7-16.

29. Soares-Miranda L, Abreu S, Silva M et al 2017 Cancer survivor study (CASUS) on colorectal patients:longitudinal study on physical activity, fitness, nutrition and its influences on quality of life, disease recurrence and survival. Rational and design. *Int J Colorectal Dis* 32(1):75-81.

30. Woods JP, Smith AJO, Bowman KJ, Thomas AL, Jones GDD (2015). Comet assay measures of DNA damage as biomarkers of irinotecan response in colorectal cancer in vitro and in vivo. *Cancer Medicine* 4(9):1309-1321.

31. Fogarty MC, Devito G, Hughes CM, Burke G, Brown JC, McEneny J, Brown DE, McClean C, Davison GW. Effect of alpha lipoic acid on mDNA damage after isolated muscle contractions. *Med Sci Sports Exerc*, 45(8), 1469.

32. Sardas S, Omurtag G, Monteiro IFC et al (2013). Assessment of DNA damage and protective role of vitamin E supplements after exhaustive exercise by comet assay in athletes. *J Clin Toxicol* 3(Special Issue 5).

33. Tanimura Y, Shimizu K, Tanabe K et al (2010) Exercise-induced oxidative DNA damage and lymphocytopenia in sedentary young males. *Med Sci Sports Exerc* 40(8):1455.

34. Tanimura Y, Shimizu K, Tanabe K et al (2010). Effects of three consecutive days exercise on lymphocyte DNA damage in young men. *Eur J Appl Physiol* 110(2):307-314.

35. Mastaloudis A, Yu TW, O'donnell RP, Frei B, Dashwood RH and Traber, MG (2004). Endurance exercise results in DNA damage as detected by the comet assay. *Free Radical Bio Medicine* 36(8):966-975.

36. Radak Z, Chung HY, Goto S. (2005) Exercise and hormesis: oxidative stress-related adaptation for successful aging. *Biogerontology* 6(1): 71-75.

37. Vallance JK, Boyle T, Courneya KS, Lynch BM (2014). Associations of objectively assessed physical activity and sedentary time with health-related quality of life among colong cancer survivors. *Cancer*, 120:2919-26.

38. Oeckinghaus, A & Ghosh, S (2009). The NF-κB family of transcription factors and its regulation. *Cold Spring Harb Perspect Biology* 1(4):a000034.

Table I. Participant characteristics

	Control Group (n=11)	Exercise Group (n=12)
Demographics:		
Age in years	62.6 (9.1)	63.6 (9.5)
Male%	54.5% (n=6)	83.3% (n=10)
Female%	45.5% (n=5)	16.7% (n=2)
Marital Status:		
Single	9.1% (n=1)	8.3% (n=1)
Married	72.7% (n=8)	75.0% (n=9)
Living with partner	18.2% (n=2)	8.3% (n=1)
Widowed	0.0% (n=0)	8.3% (n=1)
Occupation:		
Professional	45.5% (n=5)	41.6% (n=5)
Managerial	0.0% (n=0)	25.0% (n=3)
Clerical	9.0% (n=1)	16.7% (n=2)
Manual	45.5% (n=5)	16.7% (n=2)
Work Status:		
Full-time	0.0% (n=0)	25.0% (n=3)
Part-time	36.4% (n=4)	8.3% (n=1)
Long-term sick leave	9.1% (n=1)	0.0% (n=0)
Retired	54.5% (n=6)	66.7% (n=8)
Cancer Type:		
Colon	81.8% (n=9)	66.7% (n=8)
Rectal	18.2% (n=2)	33.3% (n=4)
Stage:		
1a	0% (n=0)	8.3% (n=1)
2a/2b	54.5% (n= 6)	58.3% (n=7)
3a/3b/3c	45.5% (n= 5)	33.3% (n=4)
Treatment received:		
Surgery only	18.2% (n=1)	33.3% (n=4)
Surgery & chemotherapy	72.7% (n=8)	50.0% (n=6)
Radio/Chemo & surgery	9.1% (n=1)	16.7% (n=2)

Table II: Exercise prescription variables at baseline, post intervention and follow up.

Characteristic*	**Baseline (week 0)**		**Post intervention (week 12)**		**Follow up (week 24)**	
	Intervention	*Control*	*Intervention*	*Control*	*Intervention*	*Control*
Step count	32582 (24640)	24261 (7497)	36184 (14638)	35390 (18014)	25106(16668)	13434 (15157)
Light PA	924.9 (505.8)	806.4 (340.7)	807.8 (245.5)	1020.9 (309.0)	792.9 (326.6)	817.9 (388.9)
Moderate PA	172.5 (130.8)	141.2 (90.3)	212.1 (107.5)	190.9 (140.0)	173.3 (86.2)	129.1 (93.0)
MVPA	183.2 (132.2)	146.8 (98.2)	218.7 (108.1)	205.5 (161.0)	177.6 (89.1)	130.8 (93.3)
Vigorous PA	10.7 (17.4)	5.5 (10.2)	6.5 (10.6)	14.4 (26.7)	4.3 (7.8)	1.6 (1.0)
% participants achieving 150 mins/week MVPA	56	38	59	57	63	50

* All values presented are means±SD . Step count expressed as total steps/week, light, moderate, moderate to vigorous and vigorous physical activity (PA) expressed in minutes/week.

Table III: Exercise capacity variables at baseline, post intervention and follow up.

Characteristic*	**Baseline (week 0)**		**Post intervention (week 12)**		**Follow up (week 24)**	
	Intervention	*Control*	*Intervention*	*Control*	*Intervention*	*Control*
6MWT	535(63)	506(51)	592(83)	556(51)	610(96)	576(54)
Sit-to-stand	15(6)	12(2)	18(7)	14(4)	18(5)	16(4)

***** All values presented are means±SD. 6MWT expressed in metres and sit-to-stand test (repetitions).